Community Embeddings for Friend Suggestions

Anton I. N. Begehr
Graduate School of Business
National Research University Higher School of Economics
Moscow, Russia
a.begehr@fu-berlin.de

Prof. Dr. Petr Panfilov
Graduate School of Business
National Research University Higher School of Economics
Moscow, Russia
ppanfilov@hse.ru

***Abstract*—Graphs, such as social networks, emerge naturally from various real-world situations. Recently, graph embedding methods have gained traction in data science research. Recommender systems are used in a wide range of business applications and are essential for online, e-business models to survive and strive in the contemporary market. Using graph embeddings for recommendation tasks, have the possibility of improving upon recommender systems, because of data compression, their feature vector format, and sub-quadratic time complexity. Graph and community embeddings generated with ComE BGMM+VI are used to build a recommender system for friend suggestions. ComE BGMM+VI is an alteration of the community embeddings algorithm ComE. ComE BGMM+VI applies a Bayesian Gaussian mixture model and variational inference for community embedding and detection. Recommendations are evaluated by the top-N hit-rate over users with at least 50 friends. A friend suggestions recommender system with a top-10 leave-one-out hit-rate of 43.6% and run-time optimized 32.9% is presented.**

***Index Terms*—graph, embedding, community embedding, recommendations, friend suggestions**

I. Introduction

Graphs, such as social networks, knowledge graphs, content-rating graphs, and communication networks, emerge naturally from various real-world situations. Analyzing these graphs leads to findings and understanding of the underlying structures, coherences, and dependencies. Recently, methods for embedding graph's nodes into lower-dimensional Euclidean spaces, called graph embeddings, have gained traction in multiple areas of data science research [3].

Due to the rapid growth of the internet and data accumulation, recommender systems are essential for e-business and online business models to survive and strive in the contemporary market [7]. Modern recommender systems need to take into account the huge amounts of user data generated at all times in big data systems around the world and improve recommendations instead of failing under the thrust of big data overload.

Utilizing graph embeddings for recommendation tasks, has recently gained research traction [5, 6, 4, 8]. The advantages of graph embeddings include data compression and the Euclidean feature vector format [2]. Given these advantages and provided competitive results, graph embeddings have the possibility of greatly improving upon graph-based use-cases like recommender systems.

Identify applicable funding agency here. If none, delete this.

Community Embeddings, in addition to embedding a graph's nodes through first- and second-order proximity, also preserve higher-order proximity by embedding clusters present in the graph data. The graph and community embedding algorithm ComE aims to preserve first-, second- and higher-order proximity by embedding a graph's nodes and communities [1].

This work specifically examines community embeddings for friend suggestion recommender systems and evaluates recommendations on social network graph data for the use-case of friend suggestions. Graph and community embeddings generated with ComE BGMM+VI are used to develop a friend suggestions recommender system based on the shortest distances between nodes in the embedding. Recommendations are evaluated by the top-N recommendations hit-rate of test edges. A friend suggestions recommender system with a top-10 leave-one-out hit-rate of 43.6% and run-time optimized 32.9% is presented.

II. Ease of Use

A. Maintaining the Integrity of the Specifications

The IEEEtran class file is used to format your paper and style the text. All margins, column widths, line spaces, and text fonts are prescribed; please do not alter them. You may note peculiarities. For example, the head margin measures proportionately more than is customary. This measurement and others are deliberate, using specifications that anticipate your paper as one part of the entire proceedings, and not as an independent document. Please do not revise any of the current designations.

III. Prepare Your Paper Before Styling

Before you begin to format your paper, first write and save the content as a separate text file. Complete all content and organizational editing before formatting. Please note sections III-A–III-E below for more information on proofreading, spelling and grammar.

Keep your text and graphic files separate until after the text has been formatted and styled. Do not number text heads—LaTeX will do that for you.

A. Abbreviations and Acronyms

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, ac, dc,

and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

B. Units

- Use either SI (MKS) or CGS as primary units. (SI units are encouraged.) English units may be used as secondary units (in parentheses). An exception would be the use of English units as identifiers in trade, such as "3.5-inch disk drive".
- Avoid combining SI and CGS units, such as current in amperes and magnetic field in oersteds. This often leads to confusion because equations do not balance dimensionally. If you must use mixed units, clearly state the units for each quantity that you use in an equation.
- Do not mix complete spellings and abbreviations of units: "Wb/m^2" or "webers per square meter", not "webers/m^2". Spell out units when they appear in text: ". . . a few henries", not ". . . a few H".
- Use a zero before decimal points: "0.25", not ".25". Use "cm^3", not "cc".)

C. Equations

Number equations consecutively. To make your equations more compact, you may use the solidus (/), the exp function, or appropriate exponents. Italicize Roman symbols for quantities and variables, but not Greek symbols. Use a long dash rather than a hyphen for a minus sign. Punctuate equations with commas or periods when they are part of a sentence, as in:

$$a + b = \gamma \tag{1}$$

Be sure that the symbols in your equation have been defined before or immediately following the equation. Use "(1)", not "Eq. (1)" or "equation (1)", except at the beginning of a sentence: "Equation (1) is . . ."

D. LaTeX-Specific Advice

Please use "soft" (e.g., `\eqref{Eq}`) cross references instead of "hard" references (e.g., `(1)`). That will make it possible to combine sections, add equations, or change the order of figures or citations without having to go through the file line by line.

Please don't use the `{eqnarray}` equation environment. Use `{align}` or `{IEEEeqnarray}` instead. The `{eqnarray}` environment leaves unsightly spaces around relation symbols.

Please note that the `{subequations}` environment in LaTeX will increment the main equation counter even when there are no equation numbers displayed. If you forget that, you might write an article in which the equation numbers skip from (17) to (20), causing the copy editors to wonder if you've discovered a new method of counting.

BibTeX does not work by magic. It doesn't get the bibliographic data from thin air but from .bib files. If you use BibTeX to produce a bibliography you must send the .bib files.

LaTeX can't read your mind. If you assign the same label to a subsubsection and a table, you might find that Table I has been cross referenced as Table IV-B3.

LaTeX does not have precognitive abilities. If you put a `\label` command before the command that updates the counter it's supposed to be using, the label will pick up the last counter to be cross referenced instead. In particular, a `\label` command should not go before the caption of a figure or a table.

Do not use `\nonumber` inside the `{array}` environment. It will not stop equation numbers inside `{array}` (there won't be any anyway) and it might stop a wanted equation number in the surrounding equation.

E. Some Common Mistakes

- The word "data" is plural, not singular.
- The subscript for the permeability of vacuum μ_0, and other common scientific constants, is zero with subscript formatting, not a lowercase letter "o".
- In American English, commas, semicolons, periods, question and exclamation marks are located within quotation marks only when a complete thought or name is cited, such as a title or full quotation. When quotation marks are used, instead of a bold or italic typeface, to highlight a word or phrase, punctuation should appear outside of the quotation marks. A parenthetical phrase or statement at the end of a sentence is punctuated outside of the closing parenthesis (like this). (A parenthetical sentence is punctuated within the parentheses.)
- A graph within a graph is an "inset", not an "insert". The word alternatively is preferred to the word "alternately" (unless you really mean something that alternates).
- Do not use the word "essentially" to mean "approximately" or "effectively".
- In your paper title, if the words "that uses" can accurately replace the word "using", capitalize the "u"; if not, keep using lower-cased.
- Be aware of the different meanings of the homophones "affect" and "effect", "complement" and "compliment", "discreet" and "discrete", "principal" and "principle".
- Do not confuse "imply" and "infer".
- The prefix "non" is not a word; it should be joined to the word it modifies, usually without a hyphen.
- There is no period after the "et" in the Latin abbreviation "et al.".
- The abbreviation "i.e." means "that is", and the abbreviation "e.g." means "for example".

An excellent style manual for science writers is [**b7**].

F. Authors and Affiliations

The class file is designed for, but not limited to, six authors. A minimum of one author is required for all conference articles. Author names should be listed starting from left to right and then moving down to the next line. This is the author sequence that will be used in future citations and by indexing services. Names should not be listed in columns nor

group by affiliation. Please keep your affiliations as succinct as possible (for example, do not differentiate among departments of the same organization).

G. Identify the Headings

Headings, or heads, are organizational devices that guide the reader through your paper. There are two types: component heads and text heads.

Component heads identify the different components of your paper and are not topically subordinate to each other. Examples include Acknowledgments and References and, for these, the correct style to use is "Heading 5". Use "figure caption" for your Figure captions, and "table head" for your table title. Run-in heads, such as "Abstract", will require you to apply a style (in this case, italic) in addition to the style provided by the drop down menu to differentiate the head from the text.

Text heads organize the topics on a relational, hierarchical basis. For example, the paper title is the primary text head because all subsequent material relates and elaborates on this one topic. If there are two or more sub-topics, the next level head (uppercase Roman numerals) should be used and, conversely, if there are not at least two sub-topics, then no subheads should be introduced.

H. Figures and Tables

a) Positioning Figures and Tables: Place figures and tables at the top and bottom of columns. Avoid placing them in the middle of columns. Large figures and tables may span across both columns. Figure captions should be below the figures; table heads should appear above the tables. Insert figures and tables after they are cited in the text. Use the abbreviation "Fig. 1", even at the beginning of a sentence.

TABLE I
TABLE TYPE STYLES

Table Head	**Table Column Head**		
	Table column subhead	***Subhead***	***Subhead***
copy	More table copy[a]		

[a]Sample of a Table footnote.

Fig. 1. Example of a figure caption.

Figure Labels: Use 8 point Times New Roman for Figure labels. Use words rather than symbols or abbreviations when writing Figure axis labels to avoid confusing the reader. As an example, write the quantity "Magnetization", or "Magnetization, M", not just "M". If including units in the label, present them within parentheses. Do not label axes only with units. In the example, write "Magnetization (A/m)" or "Magnetization {A[m(1)]}", not just "A/m". Do not label axes with a ratio of quantities and units. For example, write "Temperature (K)", not "Temperature/K".

ACKNOWLEDGMENT

The preferred spelling of the word "acknowledgment" in America is without an "e" after the "g". Avoid the stilted expression "one of us (R. B. G.) thanks ...". Instead, try "R. B. G. thanks...". Put sponsor acknowledgments in the unnumbered footnote on the first page.

REFERENCES

Please number citations consecutively within brackets [**b1**]. The sentence punctuation follows the bracket [**b2**]. Refer simply to the reference number, as in [**b3**]—do not use "Ref. [**b3**]" or "reference [**b3**]" except at the beginning of a sentence: "Reference [**b3**] was the first ..."

Number footnotes separately in superscripts. Place the actual footnote at the bottom of the column in which it was cited. Do not put footnotes in the abstract or reference list. Use letters for table footnotes.

Unless there are six authors or more give all authors' names; do not use "et al.". Papers that have not been published, even if they have been submitted for publication, should be cited as "unpublished" [**b4**]. Papers that have been accepted for publication should be cited as "in press" [**b5**]. Capitalize only the first word in a paper title, except for proper nouns and element symbols.

For papers published in translation journals, please give the English citation first, followed by the original foreign-language citation [**b6**].

REFERENCES

[1] Sandro Cavallari, Vincent W. Zheng, Hongyun Cai, Kevin Chen-Chuan Chang, and Erik Cambria. "Learning Community Embedding with Community Detection and Node Embedding on Graphs". In: *Proceedings of the 2017 ACM on Conference on Information and Knowledge Management*. CIKM '17. Singapore, Singapore: Association for Computing Machinery, 2017, 377–386. ISBN: 9781450349185. DOI: 10.1145/3132847.3132925. URL: https://doi.org/10.1145/3132847.3132925.

[2] Primož Godec. *Graph Embeddings — The Summary*. 2018. URL: https : / / towardsdatascience . com / graph - embeddings - the - summary - cc6075aba007 (visited on 08/27/2020).

[3] Palash Goyal and Emilio Ferrara. "Graph Embedding Techniques, Applications, and Performance: A Survey". In: *Knowledge-Based Systems* 151 (July 2018), 78–94. ISSN: 0950-7051. DOI: 10.1016/j.knosys.2018.03.022. URL: http://dx.doi.org/10.1016/j.knosys.2018.03.022.

[4] László Grad-Gyenge, Attila Kiss, and Peter Filzmoser. "Graph Embedding Based Recommendation Techniques on the Knowledge Graph". In: July 2017, pp. 354–359. DOI: 10.1145/3099023.3099096.

[5] Enrico Palumbo, Giuseppe Rizzo, Raphaël Troncy, Elena Baralis, Michele Osella, and Enrico Ferro. “An Empirical Comparison of Knowledge Graph Embeddings for Item Recommendation”. In: *DL4KGS@ESWC*. 2018.

[6] Enrico Palumbo, Giuseppe Rizzo, Raphaël Troncy, Elena Baralis, Michele Osella, and Enrico Ferro. “Knowledge Graph Embeddings with node2vec for Item Recommendation”. In: *ESWC*. 2018.

[7] Nikolaos Polatidis and Christos K. Georgiadis. “Recommender Systems: The Importance of Personalization in E-Business Environments”. In: *IJEEI* 4 (2013), pp. 32–46.

[8] Vishwas Sathish, Tanya Mehrotra, Simran Dhinwa, and Bhaskarjyoti Das. “Graph Embedding Based Hybrid Social Recommendation System”. In: *ArXiv* abs/1908.09454 (2019).